VOLUME XXIX NUMBER 4 WHOLE NUMBER 243

THE JOURNAL

OF

THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

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PUBLISHED MONTHLY
(Ten numbers per year)

April, 1935

PRINTED FOR THE SOCIETY
TORONTO: 198 COLLEGE ST.

THE JOURNAL

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VARIABILITY OF CANADIAN WINTERS

By Andrew Thomson

Abstract—The winters in Canada, east of the Rockies, are well known to vary widely in severity from year to year. The temperature records from nine stations for the past fifty years have been analyzed to discover any definite trend towards mild or severe winters in Canada and the factors are discussed which would tend to produce either cold or mild winters in various sections of Canada.

THE winter season for meteorological purposes is limited to the period from December 1 to February 28. The mean of the average temperatures of each of the three months, December, January and February, is taken to be the temperature of the winter season. A discrepancy is here introduced since February with 28 days is given the same weight as January and December with 31 days. In Canada the daily mean temperature is defined to be the average of the readings of the maximum and minimum thermometers. It would be more correct to take the average of the 24 hourly readings on a recording thermometer, but the difference between the two is slight, as is shown in the following table which is based on observations at Toronto, and the amount will be fairly constant from year to year.

Table No. 1.—Winter temperature at Toronto determined from mean of 24 hour observations and from mean of daily maximum and minimum values

	1929-30	1930-31	1931-32	1932-33	1933-34
24 hourly mean ° F.....	25.12	27.33	33.06	33.84	27.14
½ (Max. plus Min.) ° F.....	24.93	26.99	32.99	33.62	26.62
	−0.19	−0.34	−0.07	−0.22	−0.52

In the extreme northern stations a more serious inaccuracy is probably introduced through the freezing of mercury in the maxi-

mum thermometer and the consequent failure to record temperatures below minus 37° F. The winter temperatures might be slightly lower in extremely cold winters on this account.

A more subtle effect to detect in a study of the trend of temperatures arises from the changing conditions under which the observations were taken. These changes are necessarily more frequent in a rapidly growing country like Canada where observations may be begun at a country site, and in 40 or 50 years this site will be either changed or lie far within the built up area of a city. As a check on the effect of the building up of Toronto the observations taken there have been compared with those at Paris, Ontario, where temperature records have been obtained continuously in the same place by Miss Kay and her father for 40 years. This is the only station within a radius of 100 miles of Toronto where a homogeneous uninterrupted meteorological record is available.

TABLE NO. 2.—MEAN WINTER TEMPERATURES OVER FIVE YEAR PERIODS AT TORONTO AND PARIS, ONTARIO, FROM 1890 TO 1930

	1890-4	1895-9	1900-4	1905-10	1911-15	1916-20	1921-5	1926-9
Toronto	23.6	24.8	21.7	24.3	25.3	23.3	24.8	25.3
Paris	22.5	23.4	20.1	23.1	24.0	22.1	23.3	24.0
	1.1	1.4	1.6	1.2	1.3	1.2	1.5	1.3

The constancy of the difference of the winter temperatures at Toronto and Paris, Ontario, shows clearly that neither the growth of the city since 1890 nor the changed location in Toronto has had an observable effect on the recorded winter temperatures at Toronto. It is just possible that at other seasons of the year the effect of the changing foliage of trees might cause considerably larger discrepancies than found for the winter.

In the winter season, January is the coldest month in Canada, except in old Ontario, Nova Scotia and Prince Edward Island, where the coldest month is February. The reason for the long delay of the coldest weather in both regions in spite of the sun's increase in declination after December 21st is obscure. At Toronto over a period of 58 years, 1840-98, the coldest day in the year was found to be February 5th. As the area of open water over Lake Michigan and Lake Huron is considerable in many winters until

late in January, there is sufficient effect on the pressure field caused by the warm air lying over the water to deflect over Ontario the warm air masses coming up the Mississippi River valley. When the area of open water in the Great Lakes becomes greatly reduced, the polar air masses from northwestern Canada sweep forward over a uniformly cold surface. In the maritimes the polar air masses appear to pass to the northward over Labrador until late in January. After this date, possibly owing to the increasing development of the high pressure region, the polar air masses take a more southerly track over the Maritime provinces and New England.

In order to determine the temperature trend a few stations with long records were selected and the mean temperature for each region obtained from one to three stations in that region. In the western provinces Edmonton, Prince Albert and Qu'Appelle were those selected; Toronto and Montreal for eastern Canada; Halifax and St. John, N.B., for the maritimes and Victoria for British Columbia. The stations in each group resemble one another closely, the greatest variation in one group being between Edmonton and Prince Albert in the prairie section. The results for Winnipeg winters are given on account of its frequent use as an indicator of the general trend of subsequent weather in eastern Canada.

MEAN WINTER TEMPERATURE AT SELECTED CANADIAN STATIONS

Year	0 °F	1 °F	2 °F	3 °F	4 °F	5 °F	6 °F	7 °F	8 °F	9 °F
					Victoria					
189		40.2	36.5	38.9	39.5	41.1	40.9	41.3	38.8	42.5
190	41.7	42.4	41.9	41.2	42.4	42.7	38.7	41.7	37.9	37.4
191	39.3	41.7	38.7	42.3	41.1	37.0	37.6	41.0	40.7	39.6
192	41.4	37.3	38.1	42.3	40.9	44.3	41.4	40.5	37.9	38.7
193	42.9	40.1	38.3	43.5						
					Edmonton					
188				5.1	1.6	6.3	−4.0	3.3	21.7	0.9
189	15.5	13.3	9.7	7.3	9.0	11.7	13.5	13.9	11.7	12.3
190	17.0	18.8	12.1	9.5	11.8	20.0	3.0	18.6	5.4	10.2
191	6.9	15.8	12.4	12.7	11.7	7.7	3.0	3.6	3.0	3.6
192	19.3	12.2	8.8	15.7	4.1	20.1	8.3	11.7	8.5	9.7
193	26.7	10.2	9.1	15.4						
					Prince Albert					
188						−5.8	−5.3	−2.7	5.6	−10.3
189	2.3	−0.1	−5.5	−5.7	−0.7	0.2	1.7	2.4	−1.6	0.3
190	3.1	8.6	2.2	−1.2	1.7	7.4	−4.3	10.0	−2.6	2.7
191	−2.8	0.3	−0.2	5.4	3.9	−0.4	2.2	−5.6	9.2	3.7
192	8.5	2.3	1.1	8.1	−1.9	13.4	1.4	3.9	−0.8	−2.9
193	18.1	5.7	−1.0	6.9						

Qu'Appelle

Year	0 °F	1 °F	2 °F	3 °F	4 °F	5 °F	6 °F	7 °F	8 °F	9 °F
188				−3.5	−6.9	2.6	−6.8	−2.4	10.8	−3.1
189	8.7	4.7	−3.1	−0.5	3.0	6.5	6.0	6.5	0.9	4.9
190	6.4	11.0	4.6	3.1	5.6	11.1	0.8	12.3	3.4	3.9
191	0.1	3.5	4.0	9.1	8.8	1.9	−2.6	−1.7	7.4	5.2
192	12.4	4.5	2.9	11.7	3.2	15.5	4.2	6.5	2.8	5.0
193	21.2	11.3	4.6	10.0						

Winnipeg

188				−8.0	−8.0	−2.3	−8.9	−6.0	4.5	−4.0
189	4.5	2.4	−6.6	−3.5	2.3	3.3	3.3	4.2	−2.5	3.7
190	2.0	9.0	3.2	−2.9	.9	6.8	−1.6	10.2	2.6	2.2
191	.8	2.5	1.6	6.0	5.4	2.0	−4.2	−2.3	9.4	1.3
192	9.9	4.9	1.7	8.8	.5	9.5	4.1	6.1	2.4	2.9
193	13.7	10.4	1.0	1.9						

Toronto

184		27.8	22.6	25.4	26.9	22.7	24.1	28.5	22.4	27.1
185	24.9	21.1	26.3	23.4	21.1	19.6	21.4	26.3	26.7	21.4
186	23.3	25.2	26.5	24.7	21.6	23.6	23.9	19.3	25.1	24.9
187	24.0	21.0	19.3	24.7	16.6	26.5	20.9	28.2	20.5	28.8
188	18.7	29.0	20.7	21.5	17.3	21.5	19.9	21.3	24.7	30.5
189	24.6	25.7	19.4	24.0	23.0	24.4	25.3	26.2	23.0	25.1
190	23.3	23.8	24.9	17.4	18.9	28.2	21.3	24.4	27.4	24.2
191	24.2	22.9	28.1	24.8	25.1	25.5	22.2	17.9	29.6	18.6
192	28.2	26.1	23.0	26.6	24.1	24.1	24.1	26.2	25.9	25.0
193	26.7	32.7	30.0	20.1						

Montreal

187						16.2	16.2	21.0	14.7	18.7
188	14.1	20.3	12.6	13.1	12.6	14.4	12.1	11.5	18.2	18.9
189	14.0	20.4	12.1	13.4	17.3	16.3	16.7	17.3	16.7	19.2
190	14.7	17.2	16.3	9.6	9.5	20.0	11.4	16.7	16.1	18.9
191	13.0	15.6	19.5	15.6	19.1	18.2	13.5	9.5	20.2	12.0
192	19.5	15.0	13.0	17.5	15.7	16.6	16.7	18.3	19.4	17.7
193	18.6	23.0	24.5	9.0						

St. John

187										22.6
188	20.3	22.4	17.8	20.5	19.0	21.1	18.1	17.0	23.1	21.5
189	19.8	26.3	18.5	19.5	23.0	22.2	20.7	23.0	20.8	24.2
190	21.0	24.6	22.1	17.2	16.3	26.3	18.6	25.0	22.5	25.2
191	20.3	21.0	24.3	20.6	24.5	22.4	20.2	16.2	24.1	16.5
192	22.6	20.6	15.4	22.6	19.5	19.6	20.9	22.0	23.6	20.8
193	22.6	23.7	27.6	14.5						

Halifax

187										26.2
188	23.8	24.9	21.1	24.2	24.8	27.4	25.0	22.1	28.3	25.4
189	24.8	29.8	22.8	23.8	26.6	27.3	25.9	26.8	25.9	29.8
190	26.5	29.3	25.8	22.1	18.9	28.8	22.9	27.8	24.1	27.6
191	23.0	24.2	26.8	23.5	24.0	27.9	25.3	22.0	25.5	22.0
192	26.5	23.5	19.3	26.0	23.3	23.8	24.9	25.8	27.5	25.1
193	26.5	26.3	30.8	19.3						

The values for Toronto in the above table are shown in Fig. 1.

In order to determine the severity of winters in various regions of Canada, the temperature ranges which A. H. Henry used for winters in the interior of United States (*M.W.R.*, vol. 53, 1925, pp. 67-68) has been applied to Canada.

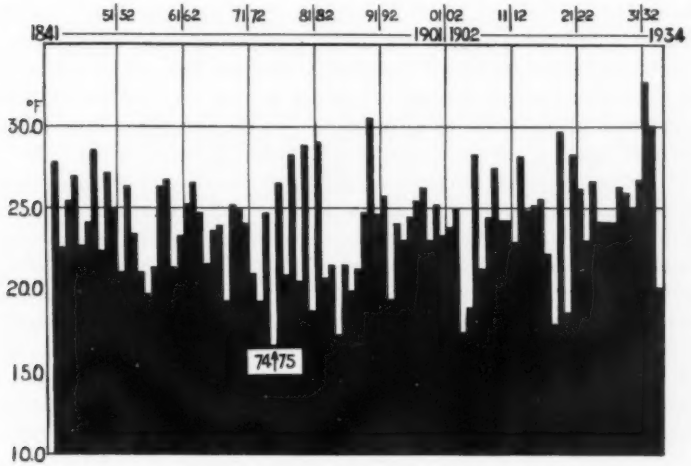


FIG. 1.—WINTER TEMPERATURE AT TORONTO 1841-1934.
The coldest winter in this period was 1874-75 and the warmest 1931-32.

TABLE NO. 3.—SEVERITY OF WINTERS IN VARIOUS REGIONS OF CANADA

Region	Mean winter temp. °F	Average winter +1.0-1.0 Winters	Mod. warm +1.1+3.0 Winters	Warm +3.1+5.0 Winters
British Columbia.....	40.3	14	13	2
Prairies.....	5.7	12	5	5
East. Can.....	20.0	16	15	8
Maritimes.....	23.2	16	13	6

Region	Very warm 5.1 up Winters	Mod. cold −1.1−3.0 Winters	Cold 3.1-5.0 Winters	Very cold −5.1 up Winters	Total −years
British Columbia.....	0	12	2	0	43
Prairies.....	9	8	5	8	52
East. Can.....	2	7	6	5	59
Maritimes.....	1	11	5	3	55

The small range and symmetry around the mean of the winter temperatures at Victoria is clearly shown in the above table. The number of moderately warm, and warm, winters equal the number of moderately cold, and cold, winters. In 43 years no winters have differed by 5° F. from the mean and only 4 differed by more than 3° F. In the prairies 17 winters out of 52 differ by more than 5° F. from the normal and 27 winters differ by more than 3° F. In the Toronto-Montreal region the large number of moderately warm winters are balanced by a few very severe winters. The maritime provinces have a range of winter temperatures very similar to those in central Canada and their proximity to the ocean has little effect in ameliorating severe conditions in these regions during winter. In the past 40 years the deviations from normal in the prairies were in the same direction as in central Canada in 31 years and opposite in 5 years. On the remaining two years the values at Toronto were exactly normal. Although the temperature variations were often in the same direction in the prairies and central Canada the actual amount of the departure from normal, winter by winter, was quite different in the two regions. Thus the temperature trends shown in figure 2 for the past 40 years were quite dissimilar from one another. Using more rigorous statistical methods the correlation coefficient between the prairies and eastern Canada is plus 0.31, where plus 1.0 would represent complete agreement and less than plus 0.4 shows only little connection between the two series of observations.

Factors Affecting the Winters in the Maritime Provinces

The Gulf stream off the coast of Nova Scotia might be expected to modify considerably the severity of the winters in the maritimes. Now the temperature of the Gulf stream has been observed to vary from year to year. If the Gulf stream exerted a direct effect on the weather in this region the winters would be milder when the temperature of the water in the Gulf stream was above normal. In the summer of 1928 the temperature of the Gulf stream off Florida was 5° C. warmer than usual (J. W. Sandstrom, *Gerland's Beitræge*, vol. 32, pp. 254-259, 1931), and the winter temperature at Halifax for 1928-29 was 2.3° F. above normal. During the

summer of 1929 this exceptionally warm water reached Iceland and the winter 1929-30 in Europe was one of the mildest on record. From a consideration of the pressure distribution alone the temperatures in the maritimes would be expected to vary in the opposite direction to the Gulf stream temperatures. During those periods

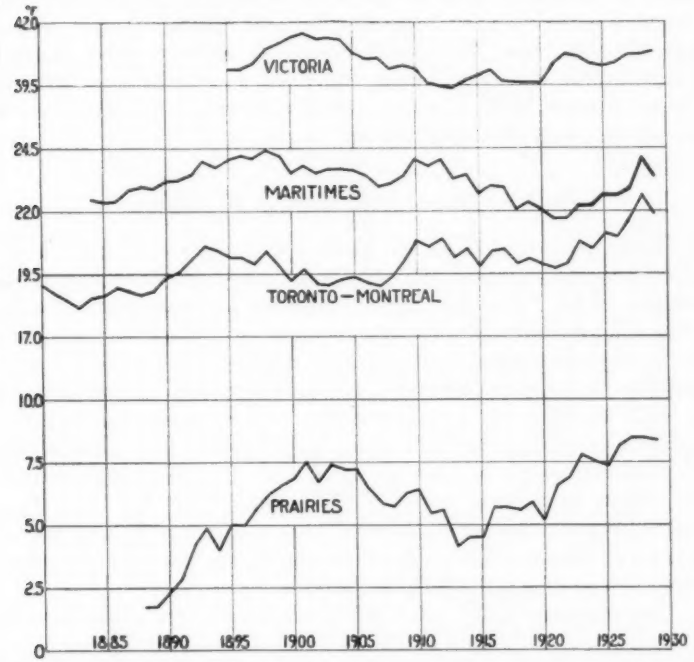


FIG. 2.—TEMPERATURE TREND OF THE WINTERS IN VARIOUS REGIONS OF CANADA.
This is based on a 10-year moving mean; i.e., the average temperature of the ten winters 1890-1900 was determined and credited to 1895. The winters have become milder in the prairie provinces and Ontario since 1880 but there is little change in the maritimes and at Victoria, B.C.

that the off-shore waters are very warm, the cyclonic circulation set up around a centre of low pressure produced by warm air would cause strong northerly winds over Nova Scotia and the temperatures there would fall. The two effects of the Gulf stream just mentioned tend to neutralize each other so that variations in the course or

temperature of the Gulf stream would not produce large variations in the temperature of the maritimes. It should be noted that when there is only slight warming up of the water so that the warmed moist air above the ocean can rise less than 2 or 3 km., the effect of the warming up is to increase the pressure, exactly the opposite effect produced by large temperature departures when the warm air column reaches up to the stratosphere (H. Worner, *Ann. d. Hydr.*, pp. 445-450, Heft XI, 1934). Thus the slightly above normal temperatures observed during the polar year over the Atlantic Ocean, August, 1932, to August, 1933, caused a very slight increase in pressure over the same region.

Factors Affecting the Winters in the Prairies

The Canadian prairies, in common with the great plains of the United States and the whole Mississippi valley, had a series of cold winters from 1882-3 to 1887-8 inclusive. These winters were followed by summers with little rainfall, and the great droughts occurring in the years 1880-8 were as severe in southern Saskatchewan as have been experienced in the past decade. From 1918-19 to 1923-24 inclusive the winters were above normal temperature over the interior of the United States. This has been ascribed by T. A. Blair to the persistence of a settled pressure distribution continuing year after year (*M.W.R.*, May, 1931, pp. 175-181). In the summers preceding the cold winters of 1883-88 the pressure was high across the North Pacific and during the summers preceding the warm winters of 1919-1924 it was low.

The characteristic feature of the weather in the prairie region during the winter season is the outbreaks of polar air entering the northwest territories along our Arctic coast line. According to Weichman (*Met. Zeit.*, 1927, p. 241) these outbreaks from the great cap of polar air occur fairly regularly every 24 days, and in certain winters, notably 1924-25, this has been the case. In other winters this periodicity has been hard to detect as an analysis is complicated on account of the fact that invading southward-moving masses, indicated by increasing pressures, have surface temperatures near or above normal. While these polar masses lie for some time in an anticyclone over the prairie region, much heat is lost by radiation

to outer space and the upper atmosphere, owing to the small moisture content of polar air. Thus the temperature of the air in the returning current at the rear of the anticyclone often falls lower than it was when the masses first entered the continent. For

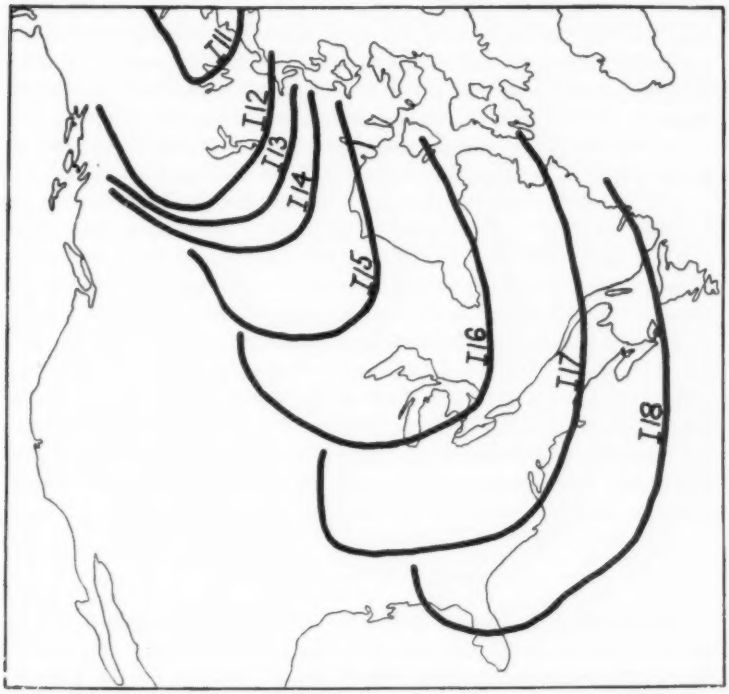


FIG. 3.—DAILY PROGRESS OF OUTBREAK OF POLAR AIR, JANUARY 11-18, 1934. Lines show position of polar front each day at 8 a.m. (Eastern Standard Time). The majority of outbreaks of polar air during the winter of 1933-34 followed this southeasterly path instead of moving directly south through the midwesten States as occurred in the winter of 1932-33. As a result the winter of 1933-34 was one of the coldest on record in eastern Canada and the maritimes but was above the normal temperature in the western states and Alberta.

example, the temperature of a polar air mass crossing the Arctic coast line at Aklavik on December 4, 1934, with a temperature of 6° F. would appear to have fallen 30° F. during the following four days. (See Fig. 3),

These cold masses existing as enormous anticyclones on the northwest part of Canada are started into motion either by a disturbance from the Pacific moving into the Rockies, or by a further building up of the anticyclone until the pressure gradient along its southern border becomes excessive. The subsequent direction of motion of these cold air masses after leaving the prairies varies considerably. In the winter of 1933-34 they moved southeast across Ontario and the maritimes, while in 1932-33 the air masses travelled directly southward across the western prairies.

A remarkably close agreement has been found by Bliss (*Memoirs, Quart. Journal Royal Met. Society*, vol. 2, no. 17) between the winter in Manitoba and the temperatures during the previous seasons at Bombay, Lahore and Allahabad in India. Following this lead, F. Groissnayr (*M.W.R.*, 1929, pp. 453-456) found the correlation between the monthly pressure departure at Nagpur, India, from January to October and the temperature of the following winter at Winnipeg was plus 0.77 with a probable error of .04 "the highest correlation ever obtained between different weather elements of widely separated stations and at disconnected times". There appears to be little if any physical reason for this extraordinary close relationship. Groissnayr has also found that the temperature during the spring season in the Great Lakes region usually follows the same direction as the winter temperature at Winnipeg.

Winters in British Columbia

The weather in British Columbia during winter depends on air moved in after a long traverse across the Pacific Ocean. The great west-to-east movement of the air in these latitudes carries the air masses bodily on to the western coast of the continent so that the climate of British Columbia is much more under the influence of the ocean than the maritime provinces. Consequently any rise or fall of the temperature of the Pacific must directly affect the temperatures on the coast. The Canadian Meteorological Service has provided a number of ships plying between ports in the orient and Canada with continuously recording thermometers in order to obtain a record of the water temperatures on the Pacific. G. F. MacEwen, of the Scripps Institute, has investigated the variation

of ocean water temperature (*Bulletin Amer. Met. Soc.*, November, 1934, pp. 249-256) and believes that it follows, to a considerable extent, the changes in the heat emitted from the sun. Sir Frederic Stupart has investigated the variableness of Canadian winters from another angle (*M.W.R.*, July, 1924, p. 351) and found that when the Pacific cyclonic centres are less intense and enter the continent further south, the winters are extremely severe. On the other hand if the cyclones on the Pacific are of such intensity that they enter British Columbia far north they prevent the formation of anti-cyclones and concomitant low temperature.

TELESCOPE MAKING FOR BEGINNERS

By H. Boyd Brydon

(A radio talk over Station C.F.C.T., Victoria, B.C., Oct. 31, 1933)

Probably all of you have visited the Dominion Astrophysical Observatory on a Saturday night and looked through the great telescope. Wonderful things were shown you with that magnificent instrument but it is likely that during the short time you were able to be at the eyepiece you could not get a very clear idea of what they really looked like. So I am sure that many of you since have wished you had a telescope of your own so that you could observe these tremendously interesting objects at your leisure.

Very well, why not make one? Not quite so big perhaps as the one at the observatory, for that telescope is six feet in diameter and cost many thousands of dollars. No, the telescope I am suggesting that you can make for yourself is say six inches in diameter and the cost complete will range from $10 to $25, depending upon the kind of mounting and support you adopt.

Now let me assure you that a six-inch telescope is not a toy by any means. It is a really useful scientific instrument with which good work can be done. Far more powerful than those with which many great discoveries were made, such as Galileo's discovery of the satellites of Jupiter and the wonderful ring system of Saturn and the periodic wax and wane of sun-spots.

Perhaps the suggestion that you can make such a telescope may surprise you and lead you to believe that I must be thinking I am speaking to expert opticians and engineers. Not at all. Please let me remind you that the subject of this little talk is "Telescope Making for Beginners" and by beginners I mean real beginners, those who have no knowledge of optics nor of handling tools and who, perhaps until this moment, have hardly dreamed of owning a fine telescope, much less of making one.

Nevertheless, surprising as it may sound, it is literally true that any one of you, man or woman, boy or girl, can make an excellent six-inch astronomical telescope at a cost of only a few dollars for

materials, which will prove a never-ending source of enjoyment and satisfaction to you.

All you need is a little perseverance, some elbow grease and a willingness to follow a few simple instructions carefully and patiently. If you will do this you will succeed in making a splendid telescope that will show you hills on the moon, 240,000 miles away, not any larger than Mt. Tolmie; that will enable you to watch Galileo's satellites of Jupiter revolving round that planet, yes, and actually to observe Jupiter itself rotating on its axis; to see Saturn's rings and several of its moons; to see the enormous whirlpools and tornadoes on the sun that we call sun-spots, many of which are so large that our earth could be dropped into them without touching the sides; to see the wonderful Orion nebula and the great nebula in Andromeda, which is as large as our whole system of visible stars and very similar to what our system would look like could we see it from Andromeda—a great spiral nebula; to see great clusters of stars such as the beautiful double cluster in the sword hand of Perseus.

Think of the immense satisfaction of being able to see these things with an instrument you made yourself. An amateur job. "The word 'amateur'," said a wise man, "means a lover of the thing ***done***, not purchased but personally achieved, 'faithfully established at the hand of a good servant of a high calling'. It implies an emotion which nothing money—bought, borrowed, rented or stolen —ever imparts, an enthusiasm without which nothing truly worth while is ever attained.

But there is much more that such a telescope will make visible. Many stars which appear to the naked eye as single points of light are really double, triple, or even quadruple; two, three or four suns revolving round their common centre of gravity, like the fly-balls of the governor of an engine. Red stars, blue stars, yellow stars that you have never seen before. These are some of the wonders of the heavens that such a telescope will enable you to see.

And not only these. There are many stars whose light is not constant—sometimes they are bright and sometimes dim. Some vary in this manner quite regularly. Their brightness at any instant can be calculated for years ahead—just like the phases of the moon or an eclipse of the sun. Other stars are quite irregular, how-

ever. No one knows just when one of these irregular variable stars will suddenly brighten up or, if normally bright, suddenly grow dim for a while and then, after a short time, go back to normal again. But what is much more interesting, no one knows *why* these stars vary thus in brightness. There are hundreds and thousands of such stars and astronomers are trying to find out why they behave in this apparently irregular manner. For astronomers, like many other people, like things to be regular and orderly. When some planet, for instance, is not where it ought to be, they get worried. Then they start to figure out why. That is how the planet Neptune came to be discovered by Adams and Leverrier in 1846 and how in 1930 the outermost known planet of our solar system, Pluto, was found, because some other planets were not on time.

Now the telescopes in our great observatories are too busy doing the work that only they can do, and so the astronomers have turned over to us amateurs the important work of observing these irregularly varying stars. Many thousands of observations have been made on them by amateurs all over the world, but many thousands more must yet be made before the essence can be distilled from these observational data which will give us the answer.

Here is something really worth while that you can do with such a telescope. Join with other amateurs in helping to solve this riddle. Your observations will be published regularly in the Reports of the Association of Variable Star Observers. Every one can help, and help in this great problem is really needed.

Then, think of the fun of becoming astronomically world-famous overnight by discovering a new star or a new comet. Mr. L. C. Peltier, an amateur astronomer, who in daytime is an automobile mechanic in the little town of Delphos in Ohio, has found two comets which are known by his name. So you see, using such a telescope is a splendid adventure in the pursuit of knowledge.

There is no hobby equal to astronomy in real interest and worthwhileness. The more you indulge in it the more fascinating it becomes. It is quite a mistake to think that you must know a lot of mathematics. It needs nothing of the kind. As a hobby astronomy is within the reach and ability of every man and woman, boy or girl who wants to try.

THE STORY OF THE ZEISS PLANETARIUM

Prepared by C. A. CHANT

ACCORDING to the doctrine of Ptolemy of Alexandria, who lived in the second century of the Christian era, the earth was the centre of the universe and all the other bodies, including our sun and the planets, revolved around it. His theory was explained in detail in his "Almagest", which was the accepted text-book of astronomy for fourteen centuries.

The Ptolemaic system may be considered to have been overthrown by Nicholas Copernicus, who was born in 1473 at Thorn, on the Vistula, now in Poland. Copernicus became a versatile scholar, studying medicine and theology in addition to astronomy. In direct opposition to Ptolemy and his then prevailing doctrine, Copernicus proposed the theory of a heliocentric universe. According to this theory the sun is the centre of the world, and around it the planets, including our earth are forever circling.

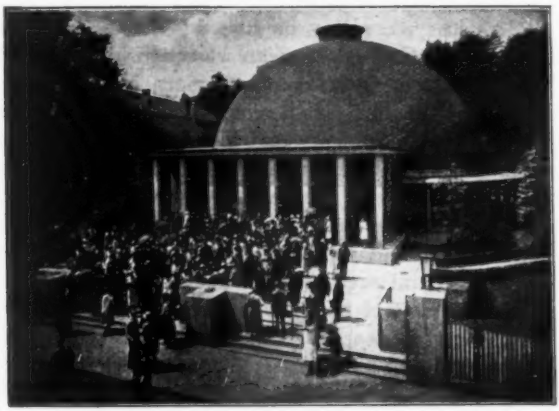
There were long and bitter disputes before the Copernican theory received general acceptance. One of the best known and most ardent champions of the new cosmic system was the distinguished Florentine philosopher, Galileo Galilei, who lived from 1564 to 1642. With the aid of the telescopes which he constructed in 1609 and later, Galileo was able, by numerous observations, to bring strong support to the Copernican doctrine. But, as we know, he had to pay for his presumption. He was accused of heresy, hailed before an inquisitorial tribunal, and compelled to recant what he had been promulgating.

In the centuries which followed, the evidence in favour of the Copernican theory grew so overwhelming that it is now universally accepted by all civilized mankind and is outside the pale of religious controversy. That the earth rotates on its axis and revolves about the sun has been verified by several physical experiments. These include the Foucault pendulum, the gyrocompass, falling bodies and the spectroscope.

As long ago as the time of Archimedes (d. 212 B.C.), men of an ingenious turn of mind attempted to make mechanical models of

the world as it was then thought to be. The object was to illustrate the movements of the sun, the moon, and the planets. It was not, however, until the Copernican doctrine of the heliocentric system had gained a firm footing, that any of these attempts met with real success.

Among the first and best known of such successful models was that of Christian Huygens, which was built in 1682 by the clock-maker Johannes van Ceulen at the Hague, and which is still preserved at the observatory of Leyden.



THE ZEISS PLANETARIUM AT JENA,
where the firm of Carl Zeiss is located.

These planetariums in the course of time were developed to a point where they became valuable means of instruction by being capable of demonstrating day and night, the seasons of the year, the phases of the moon, occultations, eclipses, and other phenomena. At the beginning of the eighteenth century, George Graham, the inventor of the compensation pendulum, devised a planetarium for Prince Eugene which showed all of these celestial phenomena. This instrument was copied, with some improvements and complementary features, in the instrument which was built by John Rowley for the Earl of Orrery. It was after this nobleman that mechanical planetariums thereafter were called "orreries". Models of this kind are to be found in many countries. One of them,

constructed in 1780 by Eise Eisinga, of Franeker, Holland, has attained fame as the Eisinga planetarium. In America, too, there are a number of such instruments. The best known are those built by David Rittenhouse, of which one is preserved in Philadelphia, while another, constructed by T. H. Barlow in 1851 and exhibited at Paris in 1867, is in Transylvania College, Lexington, Kentucky.

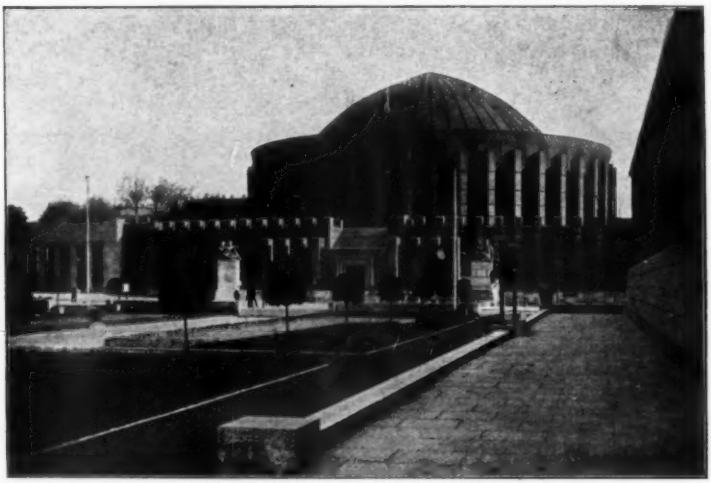
The precursor of the Zeiss planetarium may be said to be an instrument built in 1912 at Chicago by Dr. Wallace W. Atwood, then director of the Museum of the Academy of Sciences of that

THE GERMAN MUSEUM AT MUNICH
The astronomical section is at the rear.

city. This planetarium consists of a hollow sheet metal sphere 15 feet in diameter. To represent the stars, the spherical shell is pierced by numerous properly located small holes, of different sizes corresponding to various stellar magnitudes. Light thrown on the outer surface of the globe shines through the holes and gives the appearance of the starry sky to a person within the sphere. The southern portion of the sphere is cut away and through it the observer enters. The whole gives an approximately correct picture of the northern celestial hemisphere. By turning the shell about

its axis, the apparent diurnal motion of the sky can be very effectively demonstrated. It should be added that a planetarium of similar design and size had been built as long ago as 1758 by Roger Long, Lowndean professor of astronomy at Cambridge, for use in his lectures.

The greatest planetarium for showing the Copernican universe (*i.e.* the sun and the planets revolving about it) is without doubt that designed by Dr. Franz Meyer, and built by the Zeiss Works for the German Museum at Munich.



The Planetarium at Duesseldorf

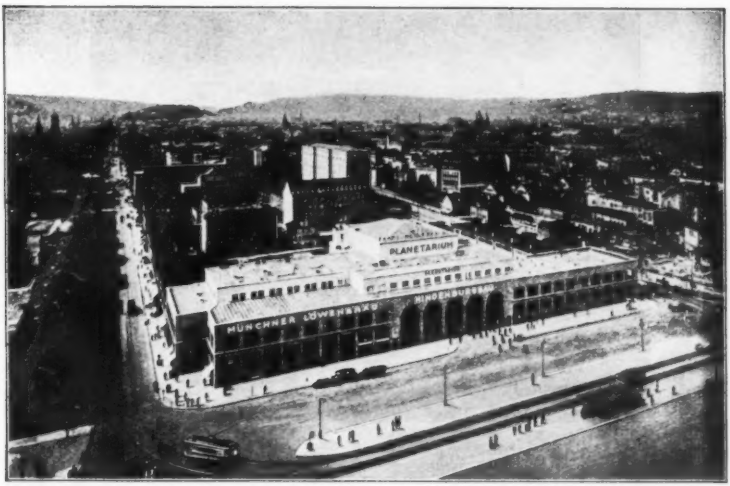
The Zeiss planetarium owes its inception to the late Max Wolf, astronomer at the University of Heidelberg. Professor Wolf suggested to Oscar von Miller, head of the famous German Museum at Munich, that he include in the Museum a planetarium of the type of Atwood's. About this suggestion, Prof. Wolf, on the occasion of the opening of the Mannheim Zeiss planetarium on April 13, 1927, wrote:

> If I praise it, I am doubly entitled to being believed sincere. For it was I who suggested that other plan for the German Museum, namely, of using a great

rotating hollow sphere, which happily has been discarded in favor of the Zeiss planetarium.

Oscar von Miller at the time transmitted Professor Wolf's suggestion to the management of the Zeiss Works. That was shortly before the World War, and years were to intervene before the idea could be realized and the first planetarium be ready for inspection.

The creator of the Zeiss planetarium was Professor W. Bauersfeld, one of the heads of the Zeiss Optical Works at Jena, Germany, who was assisted by a staff of scientists and engineers, including

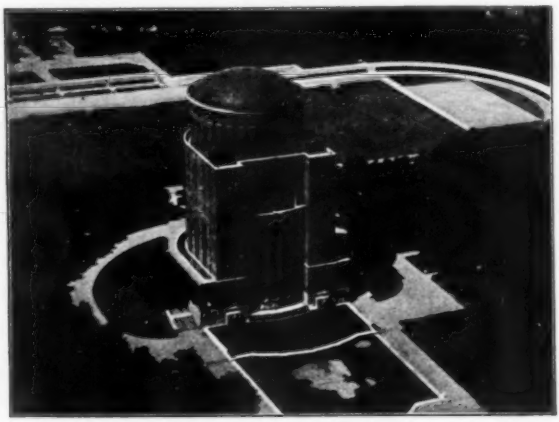


THE PLANETARIUM AT STUTTGART

astronomers, physicists, chemists, and designers. Years of unremitting labour were required to bring the complex projection instrument to its present state of high perfection. The first machine, built, as has been mentioned, for the museum at Munich, was limited in use to a certain latitude. It is able to show the heavens only as they appear to the observer at Munich. The new design of the instrument is independent of location. It shows at will the starry heavens as they are seen at any place on the earth.

The Zeiss planetarium is a living replica of the heavens, so true

as to make the observer forget he is not under nature's own sky; and yet it is so completely at man's command that days, years, and millenniums may be made to pass before the eye of the spectator in a brief space of time. The events which occur in the firmament in the course of a day, are made to happen in the planetarium at will either in four minutes, or in slightly over one minute. A whole year may be reviewed in four minutes, in one minute, or faster still, in seven seconds. And finally, the "Great Year"—the mighty change that comes to pass in the aspect of the heavens once every



The Planetarium at Hamburg

26,000 years as a result of the motion of precession—may be made to take place before the audience in a minute and a half. Nor is this all. The journey from the north pole to the south pole in the planetarium lasts but a few minutes. At any moment, however, this journey may be interrupted, to give the audience a chance to gaze upon the midnight sun, to live through the polar night, or to witness other phenomena that it falls to the lot of few men ever to encounter in reality. Thus the Zeiss planetarium overcomes one great obstacle to the study of the stars experienced by the lay observer. As with a magic wand, it speeds up the slow motions of the heavenly bodies, and, into the brief space of an hour, crowds

more events than the visitor could observe in nature by a lifetime's study.

The planetarium shows everything that is visible to the keen unaided eye under ideal conditions upon nature's heavenly canopy. The fixed stars up to magnitude 6.5, numbering about 9000 and including all known constellations, the Milky Way, nebulae, star clusters, the variable stars Mira, Algol, and Delta Cephei—all are there, to be studied at the beholder's convenience, no matter what the time of day or the weather conditions under the real sky outside

THE PLANETARIUM AT BERLIN

may be. Moving through this imposing array of fixed stars are seen the sun on his apparent course around the earth, the moon with ever changing phases, and the planets Mercury, Venus, Mars, Jupiter, and Saturn as they wend their way through the heavens. That beautiful though elusive phenomenon called the zodiacal light awaits but the command to appear. Solar and lunar eclipses, shooting stars, and comets, finally, may be shown with the aid of accessory apparatus.

For purposes of orientation and instruction, the celestial meridian and a reference line network with the celestial equator and the ecliptic may at any moment be spread over the starry vault. So may the names of the constellations, and further the figure

corresponding to each constellation as conceived by the ancients can be instantly outlined over it.

By the expedient of subduing the light of the sun, the Zeiss planetarium, moreover, shows the starry heavens not only as they are seen in nature at night, but also as they are during the daytime although they cannot be viewed then. These extraordinarily varied possibilities make the planetarium a truly ideal means of instruction and scientific entertainment.

The illusion brought about in the Zeiss planetarium is without

The Planetarium at the Hague

parallel. When the artificial firmament flashes on the view of the astonished beholder, as clear and bright as it appears in the pure air of a clear night, he has an impression of infinite space that it is impossible to get away from. The sky shows the true black-blue colour, and the starry sphere has the same appearance that characterizes its aspect in nature. So overpowering is this semblance of reality, that it affects the trained astronomer among the audience equally with the layman. There is no way of describing the experience. It is possible to describe the instrument and state what it can do, but nothing short of seeing can convey any adequate idea of the performance.

Professor Elis Strömgren of Copenhagen, Denmark, has called

the Zeiss planetarium "the wonder of Jena". Numerous astronomers from all parts of the world have visited Germany on purpose to see it. It has become an object of interest to the whole civilized world; and rightly so, because it fosters and promotes as nothing else can, a popular knowledge and an understanding of the most ancient and most noble of all the sciences—astronomy—to which mankind is indebted for many of its most inspiring advances, and which the planetarium is making more popular.

The planetarium is, indeed, an unprecedented means of instruc-

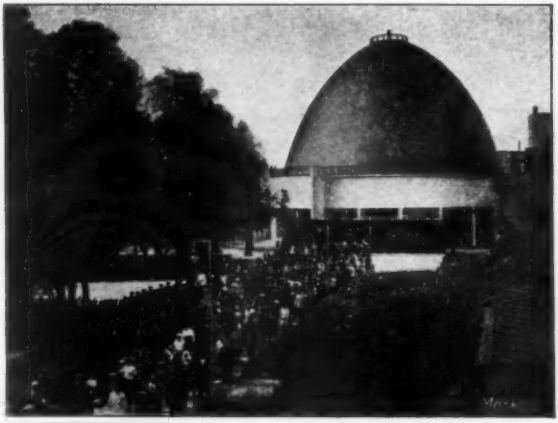
THE PLANETARIUM AT MILAN

tion and a place of wholesome entertainment which appeals alike to young and old. It is of high practical value to students of marine and aerial navigation. Above all, however, it never fails to rouse and hold the enthusiastic interest of youthful audiences. In the words of the Danish astronomer quoted before:

> Never has there been a means of instruction like this, never one as fascinating, or that has the same strong appeal to all. The planetarium is school, theatre, and moving picture, all in one. It is a classroom under the firmament, a stage on which the heavenly bodies are the actors.

A plan which has been tried with good success at Hanover and later in Berlin and Vienna in connection with the planetarium, is that of using the building also for moving pictures or lantern slide lectures of an educational and scientific character.

An example of how the Zeiss planetarium may be turned to practical use is furnished by the Italian air squadron which made the historical flight to South America. General Italo Balbo, minister of the air forces of Italy, before the flight ordered the hydroplane crews to attend the Planetarium Romanum, to acquaint



THE PLANETARIUM AT MOSCOW

them with the exact positions of the stars as they would see them on the flight over the ocean on the night of January 5, 1931, and thereby to enable the crews at all times to judge their location.

At the present time, nineteen Zeiss planetariums are in operation, not counting the one at Munich. These are in the cities of Barmen, Berlin, Chicago, Dresden, Düsseldorf, the Hague, Hamburg, Hanover, Jena, Leipsic, Milan, Mannheim, Moscow, Nuremberg, Philadelphia, Rome, Stockholm, Stuttgart, and Vienna. A planetarium for the city of Los Angeles has been erected in the centre of the Hall of Science in Griffith Park and is to begin serving the public on May 1. Another is under construction for the

American Museum of Natural History in New York and is expected to be ready on June 15.

The planetariums in Chicago, Hanover, Milan, Philadelphia, Stockholm, and Vienna have been donated by wealthy public-spirited citizens in the cause of popular education. The cost of building the Hall of Science with the Zeiss planetarium at Los Angeles will be paid out of a bequest in compliance with the will of a citizen.

The building in New York is being paid for by a loan from the

THE CHICAGO WATER-FRONT WITH THE PLANETARIUM AT THE RIGHT

Reconstruction Finance Corporation; and the instruments, both the Zeiss projection planetarium and a large Copernican planetarium, have been supplied by Mr. Charles Hayden. The planetarium for the "Haagsche Courant" is operated by the owner of that paper.

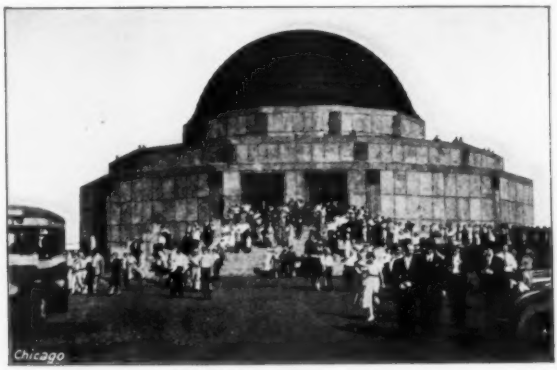
The planetarium in Chicago was donated to that city by Max Adler and bears his name. Mr. Adler's object in providing it was expressed in his presentation address:

Chicago has been striving to create, and in large measure has succeeded in creating, facilities for its citizens of today to live a life richer and more full of meaning than was available for the citizens of yesterday. Toward the creation of such opportunities I have desired to contribute.

The popular conception of the universe is too meagre; the planets and the stars are too far removed from general knowledge. In our reflections, we dwell too little upon the concept that the world and all human endeavour within it are governed by established order and too infrequently upon the truth that under the heavens everything is interrelated, even as each of us to the other.

* * * * *

The planetarium has been the subject of praise by scientists and educators.



THE ADLER PLANETARIUM AT CHICAGO

One of them has characterized it as "a school-room under the vault of heaven" and as "a drama with the celestial bodies as actors".

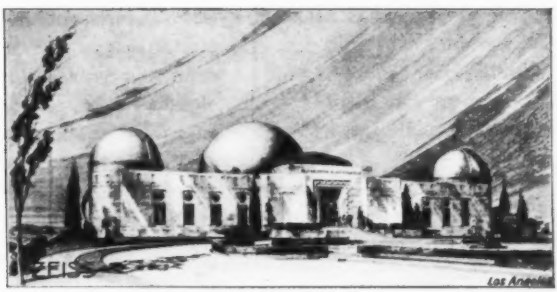
It is my hope that the youth of our city, and indeed of other cities, may through this dramatization find new interests and fresh inspiration and also that with the aid of the Planetarium and Astronomical Museum science may be advanced.

Under the able management of Professor Philip Fox the Adler Planetarium and Astronomical Museum has been an outstanding success. It opened its doors to the public on May 12, 1930, and Professor Fox states that to January 1, 1935, the attendance has been 2,878,529, which is almost equal to the population of the Province of Ontario.

The Fels Planetarium in Philadelphia was formally opened on

THE FELS PLANETARIUM AT PHILADELPHIA

November 6, 1933, and has continued since then without interruption. There are three showings a day during the school term, one in the morning, one in the afternoon and one in the evening. With the close of school the morning lecture is discontinued. On Saturdays and Sundays there are extra showings. Mr. E. D. Connelly, publicity director, under date October 99, 1934, reports that the total attendance until then was 270,666, of which number 84,619 were from the schools. The school children of Philadelphia are admitted free; all others pay a fee of twenty-five cents. The planetarium is only a part of the fine new building which houses a memorial chamber to Benjamiun Franklin, the great scientific library of the Franklin Institute, and an industrial and scientific



THE GRIFFITH PLANETARIUM AT LOS ANGELES

museum. The museum portion of the building was open to the public on January 1, 1934. The total attendance for both planetarium and museum passed the half-million mark by October 1, and the daily attendance for both is about 1,500.

The present writer has attended three Zeiss planetariums, two in Europe and one in America, and can testify to the impressive nature of the representation of the heavens and its truth to nature. There is surely no other means so excellent and so inspiring for teaching the appearance and the motions of the skies.

Whoever has witnessed a show in the Zeiss planetarium and has there been reminded of how all events in the infinite universe proceed from eternity to eternity in obedience to eternal laws, will be in the frame of mind to understand the great philosopher Emmanuel Kant, when he says:

"Two things fill my mind with ever new and ever greater wonder and reverence, the oftener and the longer I allow my mind to dwell on them—the starry heavens above, and the moral law within me."

FIVE GREAT GREEK ASTRONOMERS
(c. 408 B.C.—c. 165 A.D.)

By A. Willard Turner

Introduction

BY way of introduction, a few polemical remarks concerning the philosophy and history of astronomy may not be untimely.

In the early days of recorded Greek thought, philosophy embraced the entire range of science. Astronomy, in particular, was primordially incorporated in the cosmological speculations of the very earliest philosophers of whom we have any significant knowledge. Unfortunately, in these early schematic systems, we can scarcely expect to separate characteristics which are fundamentally scientific from those which are purely mythological, since astronomy and astrology formed an impregnable combination. Nevertheless, there is a well defined rational method inherent in these systems of philosophy which effects the germination of scientific astronomy.

Lest there are readers prone to be impatient with the cosmological schemes forming the root source of Greek astronomy, it may not be amiss to ask if modern astronomy itself is not now tending to those very philosophic speculations from which it first emerged? Further, may we suggest that the symbolism and abstractions by which astronomers solve and explain many problems to-day, are scarcely less fantastic than the speculative schema which foreshadowed astronomical development twenty-five centuries ago.

In attributing various significant discoveries to our five Greek thinkers, we have not meant to detract from the reputation of later astronomers. For example, recognition of one of our astronomers as the originator of the heliocentric theory does not deprecate the work or fame of Copernicus.

Knowledge, as we conceive it, presents a progressive evolutionary growth, wherein all constructive thought is related both to the past and to the future. Ideas have a timeless confluence, as it were, in the process of thought itself.

For us, speculations concerning future trends of scientific thought acquire greater value and sanity when they are substantiated by a comprehensive knowledge and appreciation of the past. In particular, it seems to us that the same spirit of puzzled wonder which promulgated many of the hypotheses of Greek astronomers, is apparent to-day in the work of Eddington, Jeans, De Sitter and others.

Certainly, attempts to reconstruct a glorious past in astronomical development need not obscure our vision either with respect to the accomplishments of the present or the dreams of the future.

In the following pages we have attempted to describe the chief work of five distinguished Greek astronomers. Naturally, with this numerical restriction applied to a period of almost six hundred years, we cannot hope to draw an exhaustive or coherent outline of the progress of Greek astronomy. We aim merely at present to focus attention upon the significant contributions of individual Greek astronomers.

I. EUDOXUS OF CNIDUS (c. 480 B.C.—c. 350 B.C.)

Chronologically, we have placed Eudoxus first, chiefly because it was his work which liberated scientific astronomy from the philosophic reasoning surrounding the cosmic systems hitherto advanced. Perhaps, if we regard an astronomical hypothesis as the entelechy of prior philosophic speculation, the autonomy of astronomy presents itself naturally enough. In any case, the system of concentric spheres proposed by Eudoxus to explain the seemingly lawless planetary movements, satisfies the most exacting demands of a scientific hypothesis.

Eudoxus of Cnidus in Asia Minor lived from about 408 B.C. to about 350 B.C. We are told that he was so very poor that when attending Plato's lectures in Athens he lived in Piraeus, thereby necessitating a five or six mile walk to the academy. While he was undoubtedly the greatest mathematician and astronomer of Plato's time, he was also celebrated as legislator, philosopher and physician. His pre-eminent genius as a geometer has prompted Sir T. L. Heath to write, "To Eudoxus himself geometry owes a debt which is simply incalculable, and it is doubtful, I think, whether for originality or

power, any of the ancient mathematicians except Archimedes can be put on the same plane with him".[1]

The geometric contributions of Eudoxus are too significant to be neglected here, more especially since the intrinsic essence of his astronomical system is geometric. Primarily, he invented the theory of proportion which ultimately became Book V of Euclid's Elements.[2] Aside from its purely mathematical content, this work introduced definition by abstraction, and consequently has great importance in the development of logic. Secondly, the discovery and rigorous elaboration of the method of exhaustion is credited to Eudoxus. This process enabled him to deduce various theorems concerning the areas of circles and volumes of pyramids and cones. For example, he demonstrated that the volume of a cone is one-third that of a cylinder having the same altitude and base as the cone. Subsequent developments by Archimedes in the mensuration of plane and solid figures incorporated the basic principles postulated by Eudoxus. Incidentally, the geometric contributions of Eudoxus came most opportunely, for Greek geometry at that time had reached a stage so set and closed that extreme originality and speculative power were essential to its real progress.

In astronomy, Eudoxus was probably the first Greek to give a description of the constellations,[3] and the first to propose a solar cycle of four years (three of 365 days and one of 366).[4] His unique reputation as an astronomer, however, bases itself upon the ingenious cosmic theory which he invented to account for the motions of the sun, moon, and five known planets, namely, Mercury, Venus, Mars, Jupiter, Saturn. We are told that his elaborate system—now often called the homocentric theory—formed the solution of a problem originally proposed by Plato when he suggested that panetary movements be explained by a combination of simple uniform motions. Eudoxus embodied his solution in a book on speeds, now lost. Evidence concerning the details of his system, however, may be found in Aristotle's *Metaphysics,* and in Simplicius's commentary on Aristotle's *De Cælo.*

The pure mathematical beauty and subtlety of Eudoxus' theory was first recognized by the German scholar Ideler, scarcely more than a century ago; while subsequent thorough investigations by

Schiaparelli (c. 1875) have further enhanced the reputation of Eudoxus.

While a complete and comprehensive description of the homocentric theory is beyond our province, we shall attempt to outline a few of the salient characteristics.

Specifically, Eudoxus' problem was to explain the motion of the sun, moon, and five known planets amongst the fixed stars. To effect his solution he envisaged an ingenious combination of twenty-seven concentric spheres, each revolving about a certain diameter as axis, and all having the fixed stationary earth as centre. Of the twenty-seven spheres, three were for the sun, three for the moon, twenty for the planets (four for each), and one for the fixed stars. Moreover, these sub-systems of spheres and axes were exclusive to the particular heavenly body concerned. The various speeds with which the different spheres revolved were uniform, and the diverse motions—as we should expect for that time—were circular. Apparently, the sizes of the spheres and their relative distances apart received no attention from Eudoxus, while details concerning probable causal ideas were also lacking. In brief, the system was the theoretical conception of a mathematical genius.

Obviously, one sphere, revolving uniformly in twenty-four hours about an axis through the fixed earth as centre, served to account for the apparent daily rotation of the heavens.

The moon's motion resulted from the combined circular rotations of three concentric spheres. The outermost, or first sphere, rotated like that of the fixed stars (i.e., from east to west in twenty-four hours), while a second sphere, within and concentric to the first, rotated slowly from west to east, about an axis which was perpendicular to the ecliptic. A third sphere, within and concentric to the second, revolved from east to west about an axis which was inclined to the axis of the second at an angle equal to the highest altitude reached by the moon. The moon itself was fixed on the equator of this third sphere.

The sun's motion was explained by a triadic system of spheres similar to that attached to the moon. In the case of the sun, however, the angle between the axis of the third and second spheres was less than the comparable angle for the moon. The supposition that

the sun's motion was perfectly uniform precluded any notice of the inequality of the seasons, even though it had been observed several decades earlier that the sun did not describe each of the four quadrants of its orbit in the same time. The strange feature in Eudoxus' description of the sun's motion, however, was that the great circle traced out by the sun on the third sphere was slightly inclined to the ecliptic itself.

For the explanation of planetary motion four spheres were required. The first and outermost accounted for the daily rotation in twenty-four hours, the second produced motion along the zodiac, while the two remaining spheres both rotated in the synodic period, though in opposite directions. The planet itself was fixed on the equator of the fourth sphere, and, owing to the combined motions of the third and fourth spheres, traced a ∞-shaped curve, or "hippopede", on the surface of the second sphere. The period in which the second sphere rotated was equal to one year for Mercury and Venus, and to the sidereal period of revolution for Mars, Jupiter, and Saturn. The poles of the third sphere varied for all the planets other than Mercury and Venus, while the axis of the fourth sphere was inclined to that of the third at an angle which was a constant for each planet, but a different constant for different planets. Further details of the system may be found in Dreyer.[5]

It may be of interest to notice the following table[6] which compares Eudoxus' figures for the synodic and zodiacal periods (sidereal periods) with modern values:

Synodic period

	Eudoxus	Modern Value
Saturn	13 months	378 days
Jupiter	13 months	399 days
Mars	8 months, 20 days	780 days
Mercury	110 days	116 days
Venus	19 months	584 days

Zodiacal period

	Eudoxus	Modern Value
Saturn	30 years	29 years, 166 days
Jupiter	12 years	11 years, 315 days
Mars	2 years	1 year, 322 days
Mercury	1 year	88 days[7]
Venus	1 year	225 days

However inadequate Eudoxus' system may have been, it can scarcely be dismissed as purely fantastic. While it completely failed to account for the motion of Mars, and did not explain Venus' movements satisfactorily, there can be little doubt that the system accounted tolerably well for the motions of Jupiter and Saturn. Mercury, too, was not altogether beyond the range of the theory, while the principal phenomena of the sun and the moon were described fairly well.

It is of more than passing significance that Eudoxus made use of only three factors in his determinations for each of the planets, whereas modern methods utilize no less than six.

Clearly, a scientific hypothesis designed to explain natural phenomena will be untenable if it fail to account for the observed facts. By this criterion, the homocentric theory is admittedly deficient and erroneous. For example, the theory implies that the brightness of any planet should be invariant, while ordinary observation suffices to prove otherwise. Nevertheless, the strictly theoretic and geometric perfection of Eudoxus' scheme are not impugned by empirical criticisms.

Eudoxus' system was improved somewhat by his younger contemporary, Callippus, who endeavoured to account for observed discrepancies by the addition of other spheres. Aristotle also attempted to modify the system by creating a mechanical arrangement from the abstract geometrical scheme; but this transformation merely distorted and complicated the original structure. Even so, the allegiance of the Aristotelian school to the system of spheres, ensured a high respect and sanction for Eudoxus' work.

The remarkable genius of Eudoxus is more truly appreciated if we realize that the homocentric theory was conceived more than twenty-three centuries ago, when the observational equipment existing then provided no real empirical guide to predicate or test theoretic formulation. In any case, the entire system was a beautiful exhibition of rare geometrical ingenuity and dialectical acumen, and as a speculative achievement can scarcely be surpassed.

II. HERACLIDES OF PONTUS (c. 388 B.C.—c. 315 B.C.)

In Heraclides we meet an independent thinker whose ideas and theories were not dominated by the prevailing Aristotelian school.

Reputed to be of an ancient and wealthy family, he was born at Heraclea in Pontus about 388 B.C., and lived until about 315 B.C. His personal appearance must have been rather objectionable, for we are told that he was effeminate in dress and over-corpulent.

It is quite probable that he studied under the two great philosophers, Plato and Aristole, though he did not mould his ideas after the pattern of either one. It is also possible that he attended the schools of the later Pythagoreans for some of his doctrines reflect their teachings.

Heraclides possessed an exceedingly original mind, and wrote extensively on a wide variety of subjects. His literary style was beautiful and persuasive, though he frequently embellished his works with fantastic and childish stories and was inclined to all forms of eccentricity. While none of his own writings are extant, we may infer from the allusions of later writers that Heraclides was a most individual and advanced thinker. Of his lost writings, at least two of the dialogues may have dealt with astronomy.

Although Heraclides is frequently confused with a mysterious personality, Ecphantos the Pythagorean, we shall assume with Heath that the identity of our astronomer is beyond question.

Generally speaking, Heraclides' cosmological philosophy was akin to that of the Pythagoreans. He conceived of a divine force, called mind or soul, which moved the infinite universe, and attributed divinity to the universe itself, to the planets, the earth, and the heavens. Each planet was regarded as a world suspended in the infinite æther, and possessing an earth-like body and an atmosphere (of æther). The moon was earth surrounded by mist, comets were clouds at a great height, illumined from above, and so on.

The principle doctrine for which he is famous as an astronomer is that which proclaimed the rotation of the earth on its axis. The importance of this hypothesis is best appreciated when we consider what a tremendous departure it involved from the traditional view. The earth had been regarded as stationary, and the diurnal motion of the celestial sphere was supposed to be a real motion of the sphere itself. Heraclides' idea was a direct reversal of the accepted one, for he maintained that the apparent daily rotation of the heavenly

bodies was due to the rotation of the earth about its own axis, while the celestial sphere remained at rest.

His second great astronomical contribution concerned the motion of Mercury and Venus. Specifically, Heraclides affirmed that Venus and Mercury revolved around the sun as centre. This discovery furnished a solution of the difficulty of the stationary points and retrogradations for the two planets concerned.

There are some commentators who contend that Heraclides also attributed heliocentric motion to the other known planets, (Mars, Jupiter, and Saturn). Indeed Schiaparelli claims that Heraclides was the true precursor, not only of Tycho Brahe, but of Copernicus. We are satisfied to conclude[8] that such contentions are both exaggerated and unwarranted.

In any case, Heraclides' two significant contributions to astronomical theory bear testimony to his remarkable genius, originality, and courage. When we reflect upon the overpowering influence of Aristotle, Heraclides' work is doubly appreciated, for it must have required unusual conviction and determination to present doctrines so far removed from the authoritative sanction of Aristotelian teaching.

III. ARISTARCHUS OF SAMOS (c. 310 B.C.—c. 230 B.C.)

Our third astronomer, Aristarchus of Samos, living from c. 310 B.C. to c. 230 B.C., flourished between the period marked by the geometer Euclid and that dominated by Archimedes.

While Aristarchus merits recognition chiefly as a mathematician and astronomer, he also wrote on vision, light and colours. Indeed Vitruvius in his encyclopaedic work on architecture (c. 15 B.C.) included Aristarchus amongst the few great men of antiquity whose knowledge was equally profound in all branches of learning.

Since we are convinced that Aristarchus has not received the encomium he merits from students of astronomy, we shall confine our attention solely to his astronomical contributions.

Aristarchus was the first scientist to propose a method to measure the relative distances of the sun and the moon. Although the crude character of his instruments precluded results of high accuracy it is generally agreed that his method was sound. Indeed, for nearly two

thousand years no better method was advanced. This extant treatise, "On the distances of the sun and the moon," has been translated into English by no less an authority than Sir T. L. Heath.

He is credited with the discovery of a new type of sun-dial, consisting of a concave hemispherical surface with a gnomon in the centre. Again, he gave observations of a summer solstice in 281-280 B.C., though the information supplied is somewhat vague. He also made a determination for the apparent diameter of the sun of 1/720 part of the zodiacal circle, and estimated the period for the Great Year.[9]

However significant and important the above contributions were, we have not yet mentioned that paramount achievement which anticipated Copernicus' work.

To speak of our astronomer as "the ancient Copernicus" is a perfectly legitimate appellation, for it is a well-established fact that Aristarchus was the originator of the heliocentric hypothesis formulated by Copernicus seventeen centuries later. Thus, Aristarchus explained the apparent motion of the sun by affirming the annual revolution of the earth on the circumference of a circle having the sun as a centre. His conception of the physical world implied the absolute fixity of the sphere of fixed stars and of the sun. Moreover he had a much truer appreciation of the relatively small size of this earth than his predecessors, for he regarded the sphere containing the earth's circular orbit of negligible size when compared with the sphere of fixed stars. Furthermore it is generally agreed that Aristarchus accepted Heraclides' statement that the earth turns on its axis; this rotation was implied by assuming the sphere of fixed stars to be stationary.

The following sentence translated from Archimedes' writings may reassure any skeptical reader of the authentic origin of the heliocentric theory, all the more strongly since Archimedes was a younger contemporary of Aristarchus: "His (Aristarchus') hypotheses are that the fixed stars and the sun remain unmoved, that the earth revolves about the sun in the circumference of a circle, the sun lying in the middle of the orbit, and that the sphere of the fixed stars, situated about the same centre as the sun, is so great that the circle in which he supposes the earth to revolve bears such a proportion to

the distance of the fixed stars as the centre of the sphere bears to the surface."[10]

The naturally inquisitive reader may wonder why such a significant astronomical advance has not received more attention. References to Aristarchus' system by classical authors are so few and brief that we are inclined to think that his idea was not only rejected but ignored as well. Perhaps any vestige of hope for the propagation or acceptance of this heliocentric hypothesis was buried when Hipparchus flatly reverted to the geocentric theory. However we may account for Aristarchus' comparative obscurity, we could scarcely expect a theory which proved so repugnant to the minds of the fifteenth century to be adopted naturally and enthusiastically in the fourth century B.C.

We are hopeful that the remarkable work of Aristarchus will become better known to more students of astronomy, and that as a result this great Greek thinker will be accorded the indubitable recognition due the astronomer who first postulated the great heliocentric hypothesis to explain planetary motion.

REFERENCES

[1]Heath, T. L., *Aristarchus of Samos.* (Oxford) 1913, p. 191.

[2]Smith, D. E., *History of Math.* (Ginn and Co.) 1923. Vol. I. p. 91, states "there is no definite historical sanction for this fact".

[3]Smith, *ibid.*, p. 93.

[4]Dreyer, J. L. E., *History of Planetary Systems from Thales to Kepler.* (Cambridge) 1906, p. 88.

[5]Dreyer, *ibid.*, pp. 89-107.

[6]Heath, *ibid.*, p. 202.

[7]Both Heath and Dreyer gives values of 1 year in lieu of 88 days and 225 days. Heath, p. 202. Dreyer, p. 100.

[8]Agreeing with Heath and Dreyer.

[9]It is not clear just what period he meant by this term.

[10]Heath, *The works of Archimedes,* p. 122.

(To be concluded)

METEOR NEWS

Observations relating to meteors and meteorites are cordially invited.

Summer Meteor Observations for 1935

It is not too early to begin planning now for meteor observations during this coming summer. Last year a large number of Canadian observers took part in the observations of the Perseids in the middle of August and a considerable quantity of valuable observational material was collected at this time. The preliminary report of the programme was published in the November Journal and the computation of heights and reduction of the photographic observations is now being carried out at the University of Toronto. There has recently been a noticeable increase of interest in meteor observations among Canadian amateurs and several centres of the Society are planning groups for definite programmes of meteor observation. It is hoped that members of the Society, through their active co-operation, will make it possible to carry out this summer an even more successful programme than that of 1934.

The greatest number of Perseid meteors may be expected on the three nights Aug. 10-11, 11-12, 12-13, and since full moon occurs on the 14th the hours after midnight will be more favourable for observing. The last half of July and the first half of August is, however, an excellent period for meteor observing, as the highest hourly rates are seen at this time of the year and there is the added advantage that the weather is usually mild. Hence observations need not be restricted to the three nights listed above but should be made when opportunity offers. The dark skies accompanying the new moon of July 30 will be particularly favourable for the observation of large numbers of meteors.

The writer expects to have all maps and instructions ready by the end of May or early in June and it is hoped that any readers of the Journal, who think they may have the opportunity of observing, will send in their names and addresses to the writer at the Department of Astronomy, University of Toronto, as soon as possible. It must be remembered that no telescopic equipment is required for this work, the chief requisites being enthusiasm and good eyesight.

Photographic Observations of the Leonids and Geminids

The visual observations of the Leonids and Geminids, made in 1934, have previously been reported in these pages. Three meteor spectrographs and two direct cameras were exposed at the David Dunlap Observatory during the Leonid programme and three spectrographs were exposed in North Toronto during the Geminid observations. Eastman IC special red sensitive plates were used in all the spectrographs and several makes of press plates were used in the direct cameras. No Leonid spectra were photographed, the shower in 1934 showing a marked absence of very bright meteors, and clouds seriously interfering on three out of four of the maximum nights. Two direct trails were secured, a non-Leonid on Nov. 14-15 and a first magnitude Leonid on Nov. 16-17. One Geminid spectrum was photographed which though faint shows some detail in the red. This meteor was unfortunately not observed visually as the writer was reloading plate holders at the time, but it must have been of magnitude –3 or –4 as a –2 magnitude Geminid, which appeared later in the evening at nearly the same place, failed to register. The details of the photographic programmes are listed below.

Photographic Observations

Date and Place	No. Exposures	Total Hours Exposed	Meteors Photographed
Spectrographic			
D.D.O. Nov. 14-15, 1934	15	11.8 hrs.	———
Nov. 16-17, 1934	30	15.1	———
N. Toronto, Dec. 13-14, 1934	24	16.3	1
Direct			
D.D.O. Nov. 14-15, 1934	17	3.0 hrs.	1
Nov. 16-17, 1934	35	9.2	1

P.M.M.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Lick Observatory—New Director

On July 1, 1935, Robert Grant Aitken, who was appointed director of the Lick Observatory in 1930, retires from active duty. He joined the staff over forty years ago, when Edward S. Holden, the first director, was in charge, and has become the world's chief authority on double star observations. The new director is William Hammond Wright, who has been a member of the staff for thirty-eight years. Dr. Wright is well known for his spectrographic researches on the stars and nebulae, and also for his pioneering work in planetary photography with infra-red light.

Sky-Glow from Large Cities

Mr. H. W. Barker writes as follows:

I was interested in Mr. D. W. Rosebrugh's letter regarding the sky-glow from large cities. He spoke of seeing the glow of New York City eighty miles away, as well as that of nearer places.

From the heights overlooking Lake Ontario, close to my home in Scarboro just east of Toronto, it is possible on any clear moonless night to see the lights of St. Catharines, and Buffalo and Lockport, N.Y. One evening some years ago, the visibility being good, I happened to be calling on my neighbour Mr. H. P. Eckardt (since deceased) whose home was on the cliff. In conversation I said something about this. He replied that he often saw the glow from the lights of Rochester as well. We then went out to the veranda from which there was a clear view without the interference of street lights, and sure enough, in addition to the three patches of light which I had frequently seen, there was, away off over the lake to the south-east, the glow from the lights of Rochester ninety miles or more away!

Can an Astronomer get "Lost"?

We do not mean lost in a spiritual sense, or in a London fog, or by getting too deep into one's subject. We mean really and truly lost, "orientally". As Robert W. Service puts it—

> When you're lost on the wild,
> And you're scared as a child,
> And death looks you bang in the eye.

After many arguments around the lunch table, we continue to affirm that an amateur astronomer cannot get lost, at least for a long enough time to have death look him in the eye.

Take the case of L. C. Russell, prisoner of war in Germany, whose story of escape "through swamps to freedom" appeared in the *Toronto Star Weekly* of February 16, 1935. In a totally unknown country, where he dared not inquire the way of any person he met, Russell had his compass injured so that the needle became unbalanced. He afterwards repaired it with gum which he obtained from a tree, but he says, "We lost all sense of direction,—but after a time the stars came out and we could set a course for Holland." Interviewed, he stated that the pointers of the Dipper gave him the pole star; he having learned this fundamental fact in his training as an army officer.

The writer has been told by wanderers in the Canadian wilds that it is easy to get lost in the woods, or on the prairie, or in the mountains, because "all the trees look alike, the prairie is like the sea for hundreds of miles, the mountains are bewildering, and they enclose you so that you cannot locate the valley through which you entered, etc., etc." All arguments about the stars, or the compass, are met with phrases such as "You have never been lost; you don't know how it feels; you don't know what you would do," and so on.

No, the writer has never been lost, because he has always had a sense of direction. Perhaps in an earlier life he was some kind of homing pigeon.

Of course the only way to prove he can find his way home by the stars is to go away and get lost; but that is impossible, because he cannot get lost, being an amateur astronomer.—*F.T.S.*

New Edition of the Franklin-Adams Chart

The Royal Astronomical Society is prepared to issue a third edition of the Franklin-Adams Chart of the sky provided sufficient support is forthcoming. This well known chart forms a map of the entire sky and contains 206 sheets, each covering an area $15° \times 15°$, the scale being 1° to 15 mm. The negatives show stars down to the 16th or 17th magnitudes and the chart area is 11×11 inches. The chart is in three sections: N. Pole to Dec. 22° N.; Dec. 22° N. to

22° S.; Dec. 22° S. to S. Pole. The price for the entire chart is £27 and each section may be purchased separately. Further particulars and application forms may be obtained from the Assistant Secretary, Royal Astronomical Society, Burlington House, London W.1; and orders should be sent in before October 31, 1935.

GRANT TO DR. HELEN S. HOGG

Another grant from the Gould Fund of the National Academy of Sciences has been given to Dr. Helen S. Hogg, now of Toronto, to enable her to continue her researches on variable stars in globular clusters. An account of an investigation which was carried on with the assistance of previous grants is in press as a publication of the Dominion Astrophysical Observatory.

C.A.C.

MEETINGS OF THE SOCIETY

AT LONDON

February 8, 1935.—The meeting was held at 8 p.m. in the London Life Building, Major Anundson presiding. There were 43 people present.

A current topic discussion was conducted by Mr. E. H. McKone, the HANDBOOK study was directed by Dr. H. R. Kingston, and Mr. T. C. Benson conducted the regular constellation study. A 4-inch refracting telescope, recently constructed by Mr. D. M. Henniger, was on display.

The guest speaker for the evening was Dr. Frank S. Hogg, of the Department of Astronomy at the University of Toronto. The subject of his address was "Investigations on Variable Stars." The speaker introduced his subject by a discussion of star magnitudes, pointing out that the first quantitative determination of star magnitudes was made by Hipparchus about 150 B.C. Ptolemy about 150 A.D. made a star catalogue in which the 20 brightest stars in the sky were defined to be 1st magnitude stars, while the faint stars just visible to the ordinary eye on a clear night, were regarded as 6th magnitude stars; the other four magnitudes were distributed between the 1st and 6th magnitudes. Ptolemy's basis of star magnitudes is essentially the one in use at the present time, a 6th magnitude today being technically defined to be 1/100 of the brightness of a standard first magnitude star. At present there are stars of zero and negative magnitudes.

The first observation of a variable star was made by Tycho Brahe in 1572, about 30 years before the invention of the telescope. At present there are 10 000 known variable stars, with anywhere from 4 to 20 different classifications. The speaker selected the 4-group classification and named a representative of each group, as follows: Beta Persei, Delta Cephei, Omicron Ceti, and N. Herculis. A star belonging to the first group is not a physical variable, for its variation is due to its eclipse by another star, the two stars revolving around a common centre of gravity. Stars in this group are known as Algol stars; their period of variation is from one fourth of a day to 27 years. The stars in the second group (known as Cepheid variables) are real physical variables, ranging in period from one-third of a day to 55 days. A Cepheid variable has a regular period, its variation being probably due to the expansion and contraction of the volume of the star. The stars in the third group are Long Period Variables and are known as Mira stars; Omicron Ceti for example has a period of 330 days. The fourth group of variables include the novae and irregular variables. The speaker described the work and aims of the A.A.V.S.O., pointing out that the Long Period Variables are very suitable for amateur observing. The lecture was illustrated by slides and charts.

March 8, 1935.—The meeting was preceded by a dinner at Hotel London in honour of Dr. Lachlan Gilchrist of Toronto. There were 33 members present. At 7.45 p.m. the dinner party adjourned, to reassemble at 8 p.m. in the London Life Building. The meeting was attended by 125 people. Major Anundson presiding. The following were elected members of the Society: Mr. C. F. Turner, 88 Becher St., London; Miss Marion Ellis, 280 Dufferin Ave., London.

The regular features of the programme, viz., the current topic, constellation study, HANDBOOK study, were conducted by E. H. McKone, T. C. Benson and H. R. Kingston, respectively.

Dr. R. C. Dearle, of the University of Western Ontario, introduced the guest speaker for the evening, Dr. Lachlan Gilchrist of Toronto, Dominion President of the Royal Astronomical Society of Canada. Dr. Dearle was a former student of Dr. Gilchrist's, and paid fitting tribute to Dr. Gilchrist's qualities both as a teacher and as a physicist. The subject of Dr. Gilchrist's lecture was "Physics in the Service of Astronomy". The lecture was illustrated throughout. A report of Dr. Gilchrist's address is given in the JOURNAL for March, 1935. A vote of thanks to the speaker for his interesting account of the applications of the science of physics to the science of astronomy was proposed by Dr. H. R. Kingston, and seconded by Mr. E. H. McKone; this was enthusiastically approved by the members.

G. R. MAGEE, *Secretary.*

AT VICTORIA

February 6, 1935.—A Regular Meeting was held at 8 p.m. in the Y.W.C.A. Parlors. President H. Boyd Brydon was in the chair.

The president welcomed the members and visitors to the first meeting of the spring session. He took occasion to pay tribute to the late Charles Hartley, First Vice-President of the Centre, expressing deep regret at the loss of so valued a member.

Mr. Robert Peters was called upon to present the first of a series of short talks on the constellations and other celestial phenomena. Mr. Peters referred to renewed sunspot activity, the recent partial eclipse of the sun, and the position of the moon and planets. He described in detail the interesting aspects of Orion.

Mrs. J. G. McKelvey was elected a member of the Society.

The president then addressed the meeting on the subject "Some unsolved Problems in Astronomy". Mr. Brydon pointed out that despite the progress made in our knowledge of astronomy, many problems remain unsolved. Amongst many of these problems he discussed the polarity of sun-spots, the origin of the Solar System, the marked difference in density of the inner and outer planets, Bode's law, the asteroids, the cause of craters on the moon's surface,—were they volcanic or meteoric in origin?—the cause of Saturn's

rings, the behaviour of novae and other variable stars. While many theories attempted answers to the above problems, our answer in all honesty should be "we don't know".

Mr. W. E. Harper presented an interesting slide showing the spectrum of Nova Hercules, 1934, describing how the rapid expansion of its gas envelope was measured by the Doppler effect.

AT TORONTO

February 12, 1935.—A regular meeting was held at 8.00 p.m. in the University of Toronto. In the absence of the chairman, R. A. Gray was invited to take the chair.

A letter from Calgary was read, in which it was stated that, at a meeting held there on February 2, it was decided to organize a section of the Society in that city, if sufficient prospective members could be found.

Nine candidates, nominated at the previous meeting, were duly elected to membership in the Society:

Mr. William Brough, Pettapiece, Manitoba.
Mr. C. H. Ashford, 108 Dearing Avenue, Jamestown, N.Y.
Mr. Francis Henry French, Davenport, Iowa.
Mr. S. B. Griscom, 6744 Penn Ave., Pittsburgh, Pa.
Mr. Robert B. Haller, Lindley Hall, Moscow, Idaho.
Mr. David Johnson, 11 Garfield Ave., Chicago, Ill.
Mr. Arthur L. Peck, 1927A. W. Vliet St., Milwaukee, Wis.
Lt.-Col. R. A. Williams, 229 S.W. 19th Road, Miami, Fla.
Mr. Warren J. Willis, 24824-89th Ave., Bellerose, N.Y.

Mr. Gray, librarian, expressed the hope that members would become more interested in the rapidly growing collection of excellent books in the library.

Predictions of astronomical phenomena for the following two weeks were read by the Recorder, and recent observations were reported by several members.

Miss E. J. Allin, Ph.D., research assistant and demonstrator in the Department of Physics, University of Toronto, was then introduced and addressed the audience on "Exploding Atoms—Some Recent Investigations on the Structure of the Nucleus". After discussing the various conceptions of the structure of the atom, as it was regarded through historical times, Dr. Allin explained the meaning of alpha, beta and gamma rays, electrons, protons, neutrons, negatrons and positrons, and the various phenomena connected with these constituents of the atom and the molecule. In conclusion, Dr. Allin mentioned that both in the disintegration and the building-up of atoms, there is an enormous source of energy.

A vote of thanks, on behalf of the audience, was expressed to Dr. Allin by J. R. Collins. Some interesting discussion followed.

F. L. Troyer briefly reported upon some recent events in the astronomical world.

February 26, 1935.—The meeting was held at the usual time and place. Mr. A. R. Hassard in the chair.

Six persons, nominated at the previous meeting, were duly elected to membership in the Society:

Mr. R. E. Edwards, 96 Pricefield Road, Toronto 5.
Mr. Hugh J. MacPhee, B.A., 403 Wellington St. W., Toronto.
Miss Ruth J. Northcott, B.A., 1924 Yonge Street, Toronto.
Prof. Georg Adamopoulos, 8 Rue Lamias, Athens, Greece.
Dr. H. H. Botten, 712, The Arcade, Cleveland, Ohio.
Mr. R. A. Gordon, 13436 Clifton Blvd., Lakewood, Ohio.

The last three are members-at-large.

Predictions of phenomena for the following two weeks were outlined by F. L. Troyer. Dr. P. M. Millman reported that a meeting of the Observation Committee had been held, and that various members had been appointed to advise persons interested in astronomical observation.

Dr. R. K. Young then presented his paper on "Planetary Atmospheres". First, he briefly told his audience what astronomers know about the atmospheres of the moon and planets; and then, at greater length, discussed the various observations upon which this knowledge is based.

Mercury has little, if any, atmosphere. Its observed temperature is the same as the calculated "blackbody temperature"; its albedo is practically that of rock; and there is no ring of light around the planet during a transit of the sun, as there is in the case of Venus.

Venus, on the other hand, has a comparatively heavy atmosphere, probably two-fifths as massive as that of the earth, and largely composed of carbon dioxide gas. The planet shows an atmospheric ring of light during transit of the sun. We cannot see the planet's surface, the points of the crescent are often prolonged, and the observed temperature is higher than the calculated blackbody temperature.

The moon is not large enough to hold an atmosphere, and at least three very delicate tests prove that it has none. The points of the crescent are never prolonged past the half-circumference, the rim always shows perfectly sharp during a solar eclipse, and the ingress and egress of a star during an occultation is instantaneous.

The atmosphere of the earth complicates the whole matter of observing planetary atmospheres, especially when a planet's spectrum is being considered. The light of the planet being observed must pass through the oxygen and nitrogen of our own atmosphere, and we have to sort out the spectrum lines due to the rare gases in the earth's upper atmosphere.

The chief evidence concerning the atmosphere of Mars is that we see, on the surface of the planet, a polar-cap of some substance which melts and

evaporates with the summer season and is carried to the opposite pole where it is again precipitated. This necessitates some medium for the transmission of the water vapour or other chemical constituents comprising these polar-caps. The use of infra-red photography provides evidence of an atmosphere on Mars. A luminous extension of the terminator of Mars showing what is apparently a cloud of water vapour is sometimes observed at the sunrise edge of the planet. Free oxygen is very doubtful in the Martian atmosphere, which is probably less than one-tenth as massive as the earth's.

The densities of the outer planets, Jupiter, Saturn, Uranus, and Neptune are very low. Two explanations may be possible. Either these planets consist of a small dense core covered with a thick coating of light "frozen" gases which we see as the surface, or the smaller planets, Mercury, Venus, earth and Mars, have lost most of their lighter gases, especially the elements hydrogen and helium.

The details observed on the apparent surfaces of Jupiter and Saturn shift too much to be on solid surfaces. The atmosphere of Jupiter contains extensive quantities of both methane (marsh-gas) and ammonia; Saturn is very similar, with less ammonia; and Uranus and Neptune have methane and also ammonia in smaller quantities. In the case of these outer planets, the remainder of the ammonia is likely "frozen out" because of the intense cold prevailing at great distances from the sun. Methane is still a free gas as it retains a gaseous state at extremely low temperatures.

Dr. Young explained that all the planets have lost certain chemical elements, and that this loss is regulated by the planet's velocity of escape. The sun itself has retained nearly all its original constituents because its velocity of escape is so large. When the temperatures of the planets were high, they would have lost nearly all the lighter elements not in compounds, but as the temperatures became lower, these elements would be retained even when released from these compounds. It has been calculated that if the speed of the molecule were one-third that of the velocity of escape, a planet would lose one-half its atmosphere in a few weeks; if the ratio were one-quarter, this period would be lengthened to several thousand years; and if one-fifth, the time required to lose one-half the atmosphere would be about one hundred million years.

A motion picture of "Clouds in Motion," prepared by Mr. Little of the United States Weather Bureau, was shown. Mr. J. Patterson, Director of the Meteorological Service, explained the film and the various cloud formations seen; and Mr. D. S. Archibald, also of the Meteorological Service, operated the projector.

The appreciation of the members and visitors was expressed to Dr. Young, Mr. Patterson and Mr. Archibald.

FREDERIC L. TROYER, *Recorder.*

The Royal Astronomical Society of Canada

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